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The picture looks better for closed-circuit television

High-resolution systems can be designed to transmit a wide range of data when engineers make the right tradeoffs

By F. Dan Meadows

Granger Associates, Palo Alto, Calif.

Inside a shut-down atomic reactor, a television camera moves slowly over every inch of the surface, searching for signs of deterioration. At a remote point, observers watch a monitor. As tiny cracks, fissures or other warning signs appear in sharp detail on the screen, they halt the camera and carefully examine the damage; then the search resumes.

Television systems are being used increasingly to transmit this kind of sensitive data. Such systems demand high-resolution capabilities that conventional television, adequate for home entertainment, cannot supply. Subjectively, a high-resolution tv image is defined as one that has photographic quality. Quality is further defined by three parameters: signal-to-noise ratio, tonal scale and picture sharpness. These factors, often mutually antagonistic, must be understood if the designer of a high-resolution tv system is to make intelligent tradeoffs.

Signal-to-noise ratio

Television noise is generated in several ways. Usually, random circuit noise is generated in the initial circuit stages and the noise power is proportional to the equivalent resistance, the video bandwidth, and the absolute temperature, following

the general formula $E^2 = KTR(f_2 - f_1)$ where E represents the noise voltage, K is Boltzmann's constant, T the absolute temperature, R the source resistance, and f_1 and f_2 the lower and upper frequency limits in cycles per second, of the bandpass being considered.

This type of noise appears as "snow" or graininess in the picture. In a typical vidicon camera system, the vidicon load resistor determines the value of the initial signal and also makes a major contribution to the noise. The shunt capacitance of the vidicon circuitry and the input amplifier limit the high-frequency response. High-peaking circuits, added to compensate for the high-frequency rolloff at the vidicon output, will also boost high-frequency noise. It can be seen that the greater the signal current from the vidicon the lower the load resistor need be and the less high peaking is required. Thus, the signal-to-noise ratio is improved and wider bandwidths are more readily attained.

Hum pickup produces horizontal dark bars in the picture and often causes an "S" distortion along the vertical edges of the image. Most electrical interference shows up as horizontal streaks in the picture.

Noise may obscure picture information when its level approaches that of the signal. Fortunately, the eye integrates coherent (nonchanging) information in the picture and averages out much of the noncoherent noise. Signal-to-noise ratios which are discouragingly inadequate when measured on an oscilloscope, are often acceptable when viewed on the video monitor.

Dark current

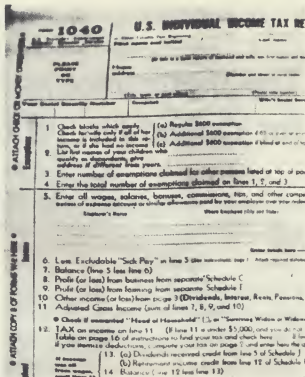
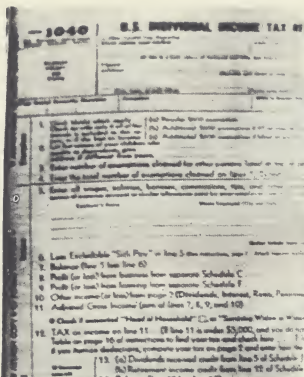
Inadequate illumination of a scene forces the use of higher operating voltages on the camera tube

The author



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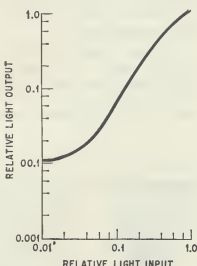
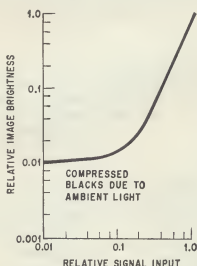
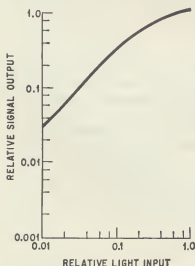
Blurred image of income tax form at the left is the way it's viewed on standard 525-line monitor—and by many taxpayers. Image at the right shows clarity possible with high-resolution 945-line television monitor.

to provide more sensitivity. This, in turn, boosts the visible level of camera-tube anomalies such as nonuniform dark current and target surface irregularities. Dark current is the background current that flows through the camera tube even in the absence of light.

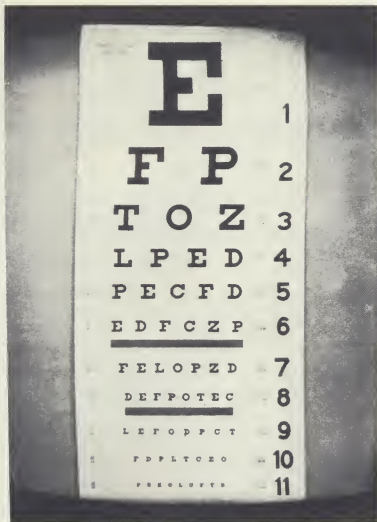
If the dark current is constant it does not affect the signal-to-noise ratio because the following amplifier is a-c coupled. However, nonuniformities during horizontal and vertical sweeps are transmitted through the system. Often these are repro-

duced as a dark ring around the outer edge of the picture, and are known as a "porthole" effect. Portholing can be caused by nonuniform deposition of the photosensitive material on the tube or by the scanning electron beam when it strikes the outer edges of the tube at an angle other than perpendicular. The signal output is proportional to the perpendicular component of the scanning beam, and because of the larger deflection angle, is smaller at the outer edges.

New vidicon types such as the 8507 have a sepa-



Linear system transfer characteristic (right), desirable for high resolution, is achieved by combining the individual characteristics of camera tube (left), in this case an image orthicon and kinescope tube (center).



Eye chart is displayed with almost photographic quality by a high-line-rate system with a 30-megacycle video bandwidth. Such systems are being used in banks, businesses and hospitals to transmit printed data.

rate mesh electrode which reduces the beam-landing error. In the case of the vidicon, the dark current increases more rapidly than the signal level (as the operating voltages are increased) and this ultimately limits the useful sensitivity of the tube.

A new vidicon tube, the Plumbicon, recently introduced by Philips Gloeilampenfabrieken, N.V., has a lead monoxide (PbO) surface instead of the usual antimony trisulfide (Sb_2S_3). Because of its very small dark current it can be used at low light levels that previously were more suited for the image orthicon than the vidicon.

A study of camera tube characteristics will indicate the minimum light level required for good signal-to-noise ratio and resolution.

Tonal scale

Tonal scale is the ability of the television system to reproduce faithfully varying shades of gray, from black to white, in the original scene. A good system can display 10 shades of gray over a brightness range of at least 30 to 1. "Black compression"

or "white clipping" can occur when the camera pickup tube is not properly adjusted, if there's poor video circuit design, or as the result of maladjustment of the contrast control on the viewing screen. Another source of trouble is external illumination that hits the face of the picture tube and washes out the blacks in the picture. High-resolution viewing requires low ambient light levels because fine detail with low contrast may be lost in the ambient light reflections and scattering.

The transfer characteristic of a television system is the plot of light output versus light input. The "gamma" is the slope of the curve when plotted on log-log paper. The gamma of a typical camera tube compensates for the inverse characteristics of the kinescope display tube so that the net result is nearly a linear curve (gamma = 1). Adjustable gamma "correction" circuits are often added to the video chain to permit the tv system to reproduce film inputs with varying gamma characteristics. Gamma correction is also used to emphasize contrast when viewing x-ray images or transmitting printed data.

The illustration on page 71 shows that the transfer functions of camera and kinescope tubes can be combined to obtain a nearly linear curve.

Picture sharpness

Although it is a subjective parameter, picture sharpness is customarily measured by viewing a standard resolution "wedge" chart. But this is only part of the story; the eye is also sensitive to the contrast between images and even if a picture has relatively poor limiting resolution, high contrast will make it seem sharp.

The concept of detail response is important to the proper evaluation of tv systems. A typical detail response curve is similar to the response curve of a high-fidelity audio system. As the electron beam in the camera pickup tube scans the optical image it generates video signals with frequencies proportional to the number of picture elements. The more detail in the picture, the higher are the generated frequencies. The amplitude of the signal decreases with the output frequency for many reasons. Among them are:

- The finite size of the scanning beam (aperture) of both the camera tube and the kinescope display tube.
- Bandwidth limitations which tend to round off what should be square waves
- Limitations of the camera lens
- Limitations of the human eye which cannot distinguish between separate images less than approximately one minute of arc ($1/60^\circ$) apart.

A detail response curve shows the relative signal output resulting from scanning vertical black and white lines on a test chart. The horizontal line number is the number of vertical black and white lines in a horizontal dimension equal to the picture height. The 100% reference level is the signal resulting from a half black-half white pattern. As more lines are scanned, the generated video fre-

quency increases and the signal output level rolls off ultimately to the point where the signal is lost in the noise. The 10% response point is usually considered the limit of useful resolution. The graph at the right shows the detail response curves of the various elements of a tv system and the response curve of the combined system.

Surprisingly, even a good lens has substantial fall-off at the higher line numbers and contributes substantially to the loss in resolution in a high resolution tv system.

The effect of "aperture" or cross-section of the scanning electron beam in the camera tube is shown in the lower graph at the right. The curve demonstrates the improvement due to increases in the focus field surrounding the tube. An increase from a 40-gauss to a 70-gauss focus field increases the signal output from 40% to 55% at 1,500 lines. This results from the tighter packing of the electron beam and the subsequent smaller scanning spot. In order to maintain one spiral loop as the beam travels down the vidicon tube, the accelerating voltage must be increased as the focus field is increased.

It has been shown that subjective sharpness can be specified by the term N_e which is the equivalent passband of the system element being evaluated.¹ N_e is simply a rectangle whose area is the same as that under the squared detail response curve. In other words, regardless of the limiting resolution as viewed from the test pattern, systems with the same area under the squared response curve have the same subjective sharpness. Even the eye has an N_e whose value varies with illumination and distance from the kinescope.

The over-all system response at any line number is the product of the individual component responses at that line number and the system. N_e can be found by the following formula:

$$N_e = \sqrt{\left(\frac{1}{N_{el}}\right)^2 + \left(\frac{1}{N_{et}}\right)^2 + \dots}$$

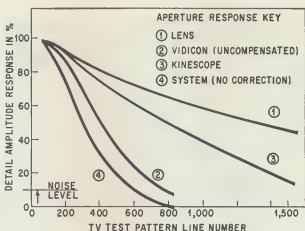
The N_e for typical components and the total system is:

Camera lens	940
Camera tube	200
Kinescope	350
Total system	170

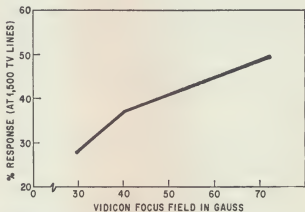
Substantial improvement in system sharpness can be obtained by introducing a compensating high-frequency boost (aperture correction) in the video amplifier. The boost must be at the frequencies and magnitude that will not boost objectionable noise levels along the signal.

Scan lines

The discussion thus far applies primarily to sharpness in the horizontal direction. Vertical resolution is determined largely by the number of scanning lines. Vertical resolution can be measured by viewing the horizontal wedges on a test pattern. The point where they merge indicates the



Response to detail of the components of a television system, measured in terms of test pattern lines. Unless compensated, each component contributes to system degradation as resolution capability is increasingly taxed.

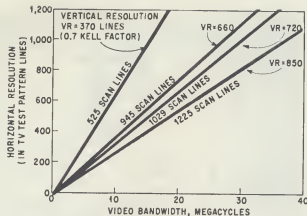


Reducing the beam cross-section in a vidicon tube by increasing the tube's magnetic focusing field can improve the camera's resolution significantly.

line number of limiting vertical resolution. This number is approximately 0.7 of the number of scanning lines. The 0.7-figure is known as the Kell factor.

All of the video signal is generated along the scan lines and no information is produced from the space between the lines. To increase the amount of detail in the vertical dimension, more scan lines are needed.

For commercial broadcast tv service the number of scanning lines is fixed by the governments of the various countries. The United States standard is 525; in England it is 405; for France the number is 819, and so on. Since closed-circuit tv is not government regulated, the scan rate becomes a matter of design choice. Systems with scanning rates up to 1,225 lines are available off the shelf. For good video transmission of alphanumeric data at least 7, and preferably 10, scan lines should pass through each character. Thus a 525-line system would require character sizes 2% of the picture



For a given number of lines in the display raster, video bandwidth must be increased to achieve higher horizontal resolution. The Kell factor referred to relates the number of scan lines to vertical resolution of the system.

height. A 1,029-line system can reproduce characters whose size is only 1% of the picture height, making it possible to view twice as much data with a 1,029-line system as with a 525 line system.

Unfortunately, the designer's job means more than just doubling the sweep frequency in order to get twice as many scan lines. Doubling of the number of lines in the same frame time (usually 1/30 second) requires doubling the linear velocity of the scanning beam. The available signal pulse rise time is now halved and unless the bandwidth of the system is increased in proportion to the increase in number of scan lines, the horizontal resolution suffers in exact proportion to the increase in vertical resolution.

A good 525-line tv system with a 10-megacycle bandwidth can reproduce one-half a typewritten page, $8\frac{1}{2} \times 11$ inches, with satisfactory results. However, it cannot reproduce a full page satisfactorily. The task becomes even more difficult if the data is of random nature, such as alphanumeric output from a computer, because the mind cannot fill in missing information. On the other hand, a high-line-rate system with a 30-Mc video bandwidth can produce an image of almost photographic clarity.

Broader use

Some typical applications of high-resolution tv capabilities include its use in commercial establishments to transmit printed data from floor to floor using a very simple transmitting console and a camera suspended above an illuminated table. The copy is placed on the table in a predetermined position and the image is sent to various viewing locations throughout the building, eliminating the need for messengers to deliver copy from file locations to the user.

Large hospitals file patient's medical records in a basement area and transmit the data via closed-circuit television to various viewing areas throughout the hospital.

Very sophisticated television display systems are in use at the Manned Spacecraft Center in Hous-

ton, at the North American Air Defense Command in Colorado Springs, at the Satellite Test Center in Sunnyvale, Calif., and at the Jet Propulsion Laboratory in Pasadena, Calif. Multiple camera and viewing positions permit personnel to have immediate access to information posted on situation display boards in other areas; to switch to selected Teletype images; to view maps of geographical areas and weather conditions; and to view the printed output of computers. Fingertip controls permit the selection of as many as 200 sources of data at one viewing console in a fraction of a second.

High-resolution tv equipment is being used to investigate matter through high-powered microscopes. One system at the University of California Radiation Laboratories views tracks left by the disintegration of atomic particles through a film emulsion. The video output is processed and fed into a computer which analyzes six different sets of data for each track. Track information, less than one micron in size, is analyzed by the tv system through a microscope with a magnification of 2500X. A similar technique is used by a British manufacturer in metallurgical applications to measure inclusions, volume fraction, grain size, and size distribution.

The Picker X-Ray Corp. of Cleveland offers a very-high-resolution tv system that uses an x-ray-sensitive vidicon tube to examine small components such as transistors, diodes, capacitors, relays, for minute flaws. A solder ball only 0.006 inch in diameter has been detected inside a TO-5 transistor housing.

Another company, the Rucker Manufacturing Co. of Oakland, Calif., is constructing a large centrifuge which will mount a high-resolution tv camera to observe the effects of 100-g acceleration on sample objects. The photographic quality of the image will permit the discovery of very small distortions which would be undetectable with tv systems of conventional design.

The Federal Aviation Agency has tested systems for use at airports to observe taxiing aircraft that are out of view of the controller in the tower. High-resolution tv systems permit the reading of identification numbers on aircraft at distances that are twice the capability of conventional tv systems. A tradeoff for such an application would be the use of a wide-angle lens that would permit four times the area of view with the same resolution as could be obtained by a conventional system with one-fourth of that field of view.

In one military application, the use of high-resolution tv cameras on radar dishes permits visual observation of missiles at limiting ranges more than twice that possible through the use of conventional television designs.

Reference

1. "Image Gradation, Graininess and Sharpness in Television and Motion Picture Systems," *Journal S.M.P.T.E.*, August, 1953.